PREDICTION OF FATIGUE LIFE ON LOWER SUSPENSION ARM SUBJECTED TO VARIABLE AMPLITUDE LOADING

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this report and in my opinion this report is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted in candidate of any other degree.

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ABSTRACT

This project focuses on the finite element based fatigue life prediction of lower suspension arm subjected to variable amplitude loading using different fatigue methods. Objectives of this project are to predict fatigue life of the lower suspension arm using stress-life and strain-life methods, to investigate the effect of the mean stress and to identify the suitable material for the suspension arm. The lower suspension arm was developed using computer aided design software. The finite element modeling and analysis were performed utilizing the finite element analysis code. The finite element analysis was performed using MSC.NASTRAN code using the linear elastic approach. In addition, the fatigue life analysis was performed using the stress-life and strain-life approach subjected to variable amplitude loading. The three types of variable amplitude are considered including positive mean loading (SAETRN), compressive mean loading (SAESUS) and zero mean loading (SAEBKT). It can be seen that TET10 mesh and maximum principal stress were captured the maximum stress. From the fatigue analysis, Goodman method is predict the conservative result when subjected to SAETRN and SAESUS loading while SWT method is applicable in SAEBKT loading. Stress-life is capable to give higher fatigue life when subjected to SAEBKT while strain-life method is applicable to give higher fatigue life when subjected to SAETRN and SAESUS. From the material optimization, 7175-T73 aluminum alloy is suitable material of the lower suspension arm.

ABSTRAK

Projek ini mengfokuskan unsur terhingga berdasarkan jangka hayat lesu “lower suspension arm” di bawah pengaruh jenis bebanan amplitud berubah yang menggunakan kaedah jangka hayat lesu yang berlainan. Objektif projek ini ialah meramalkan jangka hayat lesu “lower suspension arm” menggunakan kaedah kehidupan tekanan dan kehidupan regangan, menyiasat kesan daripada tegasan min dan menentukan bahan yang sesuai untuk “lower suspension arm”. “Lower suspension arm” distrukturkan dengan perisian lukisan bantuan komputer. Pengesahan model unsur dan analisis unsur dibangunkan menggunakan unsur terhingga berdasarkan kod analisis lesu. Analisis unsur terhingga dijalankan dengan kod MSC.NASTRAN menggunakan pendekatan elastic linear. Dengan itu, analisis jangka hayat lesu dijalankan menggunakan kaedah kehidupan tekanan dan kehidupan regangan dibawah pengaruh jenis bebanan amplitud berubah. Tiga jenis bebanan amplitud berubah diambil kira termasuk bebanan min positif (SAETRN), bebanan min mampatan (SAESUS) dan bebanan min sifar (SAEBKT). Jaringan TET10 dan prinsip tekanan maksimum diambil kira untuk analisis ini dan kawasan kritikal yang dititikberatkan ialah pada nod (8408). Daripada keputusan yang didapati, pembetulan tegasan Goodman menjangkakan kaedah yang konsevertif apabila dikenakan bebanan SAETRN dan SAESUS, manakala kaedah Smith-Watson Topper (SWT) boleh diguna pada bebanan SAEBKT. Kehidupan tekanan mampu meningkatkan hayat lesu apabila dikenakan bebanan SAEBKT, manakala kehidupan regangan dapat dipakai untuk meningkatkan hayat lesu apabila dikenakan bebanan SAETRN dan SAESUS. Daripada pengoptimuman bahan, aluminum alloy 7175-T73 ialah bahan yang paling sesuai untuk “lower suspension arm”.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ε_e	Elastic component of the cyclic strain amplitude
c	Fatigue ductility exponent
$\frac{\Delta\varepsilon}{2}$	Strain amplitude
N_f	No of cycle to failure
ε'_f	Fatigue ductility coefficient
b	Fatigue strength exponent
E	Modulus of elasticity
σ_o	Local mean stress
σ_{max}	Local maximum stress
σ'_f	Fatigue strength coefficient

LIST OF ABBREVIATIONS

Al	Aluminum
CAD	Computer-aided design
CAE	Computer-aided engineering
SWT	Smith-Watson-Topper
FE	Finite element
FFM	Finite element modeling
SAETRN	Postive mean loading
SAESUS	Negative mean loading
SAEBKT	Bracket mean loading
MBD	Multibody dynamics
LFC	Low fatigue cycle
TET	Tetrahedral
SAE	Society of Automotive Engineers

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Suspension is the system of linkages and springs or shocks that allows the wheels to move up and down independent of the body. This is important for absorbing bumps in rough terrain, gracefully landing jumps, and getting the right amount of body lean and weight transfer in turns. Both end of this component are fixed to the wheel and the chassis. Suspension components, along with wheel rims and brake components are un-sprung masses, which make weight reduction important for ride quality and response as well as for reducing the total vehicle weight. Every automotive suspension has two goals, passenger comfort and vehicle control. Comfort is provided by isolating the vehicle's passengers from road disturbances like bumps or potholes. Control is achieved by keeping the car body from rolling and pitching excessively, and maintaining good contact between the tire and the road.

The safety of the lower suspension arm can be analyzed by the finite element analysis. The safety aspect of the component is the important factor to develop the automotive industry. The most of the failure observed in the real structure and mechanical component are due to the fatigue. In the design of the real system subjected to the environment loadings, both the fatigue strength and dynamic properties of the external loads are important. In automotive industry, aluminium (Al) alloy has limited usage due to their higher cost and less developed manufacturing process compared to steels. However, Al alloy has the advantage of lower weight and therefore has been used increasingly in car industry for the last 30 years, mainly as engine block, engine parts, brake components, steering components and suspension arms where significant weight can be achieved Kyrre (2006). The increasing use of Al is due to the safety, environmental and performance benefits that aluminum offers, as well as the improved fuel consumption because of light weight.

1.2 PROBLEM STATEMENT

One of the important structural limitations of an aluminium alloy is its fatigue properties. This study is aimed at the automotive industry, more specifically a wrought aluminium suspension system, where safety is of great concern Kyrre (2006). Most of the time to failure consists of crack initiation and a conservative approach is to denote the component as failed when a crack has initiated. This simplification allows designers to use linear elastic stress results obtained from multibody dynamic FE (finite element) simulations for fatigue life analysis. The lower suspension arm is facing the vibration from the variation of road surface. Therefore it is subjected to cyclic loading and it is consequently prone to fatigue damage. The stress from the wheel unit and shock absorber are acting on the lower suspension. The best design of the lower suspension arm is considered for benefit of the cost management of the production. The best material that will be used for the manufacturing process of the component is important to predict the life.

1.3 SCOPE OF STUDY

This study is concentrates on the stress-life and strain-life approach under variable amplitude loading. The scopes of study are structural modeling, finite element modeling (FEM), finite element analysis (FEA), fatigue analysis, and material optimization.

1.4 OBJECTIVES OF THE PROJECT

The objectives of the project are as follow:

i. To predict the fatigue life of suspension arm using stress-life and strain-life method and identify the critical location.

ii. To investigate the influence of the mean stress.
iii. To optimize the material for the suspension arm.

1.5 OVERVIEW OF THE REPORT

Chapter 1 gives the brief the content and background of the project. The problem statement, scope of study and objectives are also included in this chapter. Chapter 2 discusses about variable amplitude loading, stress-life method and strain-life method. Chapter 3 presents the development of methodology, finite element modeling and analysis, fatigue life prediction technique and linear elastic analysis. Chapter 4 discusses the result of the project. Chapter 5 presents the conclusions of the project, and recommendations for the future work.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of the past research related to the fatigue life method, variable amplitude loading, and stress-life and strain-life method. The review is organized chronologically so as to offer approaching to how research hard works have laid the base for subsequent studies, including the present research effort. The review is fairly detailed so that the present research effort can be properly modified to add to the present body of literature as well as to justify the scope and direction of present research effort.

2.2 FATIGUE LIFE PREDICTION METHOD

Fatigue analysis can be used to determine how long the component can maintain in a given service condition. In general, fatigue life refers to the ability of a component to function in the presence of defect for a given loading. In practice, the predominant failure mode is fatigue and hence, the term fatigue life analysis was used to describe the analysis of the fatigue performance. Takahashi et al. (2008) were studied on creep-fatigue life prediction methods for low-carbon nitrogen-controlled 316 stainless steel (316FR). The authors were conducted long-term creep and creep-fatigue tests for several products of this steel. Superiority of the ductility exhaustion approach against time fraction approach was made clear. Afterwards, additional tests at lower strain range or longer hold time were started to evaluate the applicability to longer-term region. Some new data have been obtained from these tests and the observations obtained in the early stage were evaluated again. In order to address the concerns about applicability of the life prediction method to multiaxial stress states, biaxial fatigue and creep-fatigue tests using cruciform specimens were additionally performed during this phase of the program.

Kyrre (2006) was investigated the fatigue assessment of aluminium suspension arm. Fatigue life prediction from finite element analysis has been discussed. Although the methods can be used for all structural alloys, author focuses on aluminium alloys in automotive structures. The software package nSoft was used for fatigue life prediction and Fedem is used for the dynamic simulations. The author concluded that the dynamic finite element analysis was very computationally intensive. The model must therefore be simple, possibly confined to separate sections of the vehicle. Then the accuracy what was required for static analysis required, since small inaccuracies in peak stresses affect the life prediction can be determined significantly. This was shown for a mesh typically used in static strength evaluations. The mesh was converted using higher order elements and compared to the initial mesh. The new mesh proved to be much more conservative in fatigue life predictions. He applied the Smith-Watson-Topper (SWT) parameter and Morrow mean stress correction and found that stress-life was better correlation at high fatigue life, but the strain-life method must be used if plastic overloads are observed.

Ås et al. (2008) were studied surface roughness characterization for fatigue life predictions using finite element analysis. The authors were established a method to improve the fatigue life prediction of components with rough surfaces. A new method was proposed, in which microscopic surface measurements are used to create finite element models of surface topography. The influence of surface roughness on fatigue life can then be based on stress solutions instead of empirically derived reduction factors. Conle and Mousseau (1991) used the vehicle simulation and finite element result to generate the fatigue life contours for the chassis component using automotive proving ground load history result combine with the computational techniques. They concluded that the combination of the dynamics modeling, finite element analysis is the practical techniques for the fatigue design of the automotive component.

Kyrre et al. (2005) were conducted the fatigue life prediction of suspension arm using finite element analysis of surface topography. They concluded that fatigue strength of the structure is highly depending on the surface quality. Current methods to predict fatigue life rely on empirical relations between geometric surface parameters and observed endurance lives. The uncertainty associated with these methods is typically high, since parameters based on geometrical averages can fail to describe important characteristics of surface topography. Then they proposed a new approach where detailed finite element analysis of surface topography is used as a foundation for fatigue life prediction.

Kim et al. (2002) were studied a method for simulating the vehicles dynamic loads but they add durability assessment. For their multibody dynamic analysis, they used DADS and a flexible body model. The model was for a transit bus. For their dynamic stress analysis, MSC.NASTRAN was used. The fatigue life was then calculated using a local strain approach. From the fatigue life, it was found that the majority of the fatigue damage occurred over a frequency range that depend on terrain traveled (service or accelerated test course). This showed that the actual service environment could be simulated instead of using an accelerated testing environment.

Nadot and Denier (2003) were studied fatigue phenomena for nodular cast iron automotive suspension arms. They found that the major parameter influencing fatigue failure of casting components are casting defects. The high cycle fatigue behaviour is controlled mainly by surface defects such as dross defects and oxides while the low cycle fatigue is governed by multiple cracks initiated independently from casting defects.

Shim and Kim (2008) was studied the cause of failure and optimization of a V-belt pulley considering fatigue life uncertainty in automotive applications. Authors also analyzed a critical part by using plastic processing methods and investigated the cause of failure. The applied stress distribution of the pulley under high-tension and torque was obtained by using FEA. Based on these results, the fatigue life of the pulley considering the variation in the fatigue strength was estimated with a durability analysis simulator. A study on the shape of the optimal design was performed to increase the fatigue life of the pulley, while minimizing the weight of the V-belt pulley in the compressor system of a vehicle.

Rahman et al. (2008) were studied finite element based fatigue life prediction of cylinder head for two-stroke linear engine using stress-life approach. Fatigue stress-life approach was used and sensitivity analysis on fatigue life is discussed. Stresses obtained previously are employed as input for the fatigue life. From the result, it was shown that the Goodman mean stress correction method is predicted more conservative (minimum life) results. It was found to differ considerably the compressive and tensile mean stresses to give noticeable advantages and fond to be design criteria.

The fatigue strain-life approach involves the techniques for converting the loading history, geometry, and materials properties (monotonic and cyclic) input into a fatigue life prediction. The operations involved in the prediction process must be performed sequentially. First, the stress and strain at the critical region are estimated, and the rainflow cycle counting method Matsuishi and Endo (1968) is then used to reduce the load-time history based on the peak-valley sequential. The next step is to use the finite element method to convert the reduced load-time history into a strain-time history and also to calculate the stress and strain in the highly stressed area. Then, the crack initiation methods are employed to predict the fatigue life. The simple linear hypothesis proposed by Palmgren, (1924) and Miner (1945) is used to accumulate fatigue damage. Finally, the damage values for all cycles are summed until a critical damage sum (failure criteria) is reached.

In order to perform fatigue life analysis and to apply the stress-strain approach in complex structures, Conle and Chu (1977) used the strain-life result which is simulated using three-dimensional models to evaluate the fatigue damage. After the complex load history was reduced to an elastic stress history for each critical element, a neuber plasticity correction method was used to correct the plastic behavior. Elastic unit load analysis using strength of materials and an elastic finite element analysis model combined with a superposition procedure of each load point’s service history was proposed. Savaidis (2001) verified that the local strain approach is suitable for a fatigue life evaluation. In this study, it is consider that the local strain approach using the Smith-Watson-Toper (SWT) strain-life model is able to represent and to estimate the parameters. These include mean stress effects, load sequence effects above and below the endurance limit, and manufacturing process effects such as surface treatment and residual stresses, and also stated by Juvinall and Marshek (2000).

Rahman et al. (2009) were conducted fatigue life prediction of lower suspension arm using strain-life approach. From the fatigue analysis, Smith-Watson-Topper mean stress correction was conservative method when subjected to SAETRN loading, while Coffin-Manson model is applicable when subjected to SAESUS and SAEBRKT loading. From the material optimization, 7075-T6 aluminum alloy is suitable material of the suspension arm.

2.3 VARIABLE AMPLITUDE LOADING

When components are subjected to variable amplitude service loads, additional uncertainties arise, whether the loading in laboratory tests related to the loads that could be expected to appear. Traditionally this problem is solved by using the simplifying assumption of damage accumulation, and constant amplitude tests in laboratory are transformed to variable amplitude severity by the Palmgren-Miner rule which says that a load cycle with amplitude *Si* adds to the cumulative damage *D*, a quantity (*1*/Ni). Here, Ni denotes the fatigue life under constant amplitude loading with amplitude *Si* and n_i is the number of load cycles at this amplitude.

$$\mathrm{D} = \sum_{i=1}^{m} \frac{n_i}{N_i} \tag{2.1}$$

The lack of validity of this accumulation rule has been demonstrated in many applications and in consequence its usage will introduce uncertainties which must be compensated for by safety factors. One possible way to diminish the deviations from the damage accumulation rule is to perform the laboratory experiments closer to the service behaviour with respect to the loads. A method for establishing a Wohler curve based on variable amplitude loads has recently been developed and is presented in a parallel paper Johannesson et al. (2005). The use of this method should be customized to each specific application by performing laboratory tests with load spectra covering different service requirements. One idea is that service measurements are used to establish a few reference load spectra for use in laboratory tests. Based on the resulting variable amplitude Wohler curve, fatigue life can be predicted for load spectra similar to the reference types.

Svensson et al. (2005) was conducted the fatigue life prediction based on variable amplitude tests-specific applications. Three engineering components have been tested with both constant amplitude loading and different load spectra and the results are analysed by means of a new evaluation method. The method relies on the Palmgren-Miner hypothesis, but offers the opportunity to approve the hypothesis validity by narrowing the domain of its application in accordance with a specific situation. In the first case automotive spot weld components are tested with two different synthetic spectra and the result is extrapolated to new service spectra. In the second case, the fatigue properties of a rock drill component are analyzed both by constant amplitude tests and by spectrum tests and the two reference test sets are compared. In the third case, butt welded mild steel is analyzed with respect to different load level crossing properties and different irregularity factors.

Molent et al. (2007) was evaluated the spectrum fatigue crack growth using variable amplitude data. This paper summarizes a recent semi-empirical model that appears to be capable of producing more accurate fatigue life predictions using flight load spectra based on realistic in-service usage. The new model described here provides an alternative means for the interpretation of full-scale and coupon fatigue test data, and can also be used to make reliable life predictions for a range of situations. This is a very important capability, particularly where only a single full-scale fatigue test can be afforded and should lead to more economical utilization of airframes.

Rahman et al. (2007a) were studied about finite element based durability assessment in a two- stroke free piston linear engine component using variable amplitude loading. Authors discussed the finite element analysis to predict the fatigue life and identify the critical locations of the component. The effect of mean stress on the fatigue life also investigated. The linear static finite element analysis was performed using MSC. NASTRAN. The result was capable of showing the contour plots of the fatigue life histogram and damage histogram at the most critical location.

Nolting et al. (2008) was investigated the effect of variable amplitude loading on the fatigue life and failure mode of adhesively bonded double strap (DS) joints made from clad and bare 2024-T3 aluminum. They concluded that the fatigue life of a variable amplitude loading spectra can be calculated with reasonable accuracy using an effective stress range vs. life fatigue curve. The effective stress range vs. failure life curve is dependent on the bond geometry and therefore this curve must be developed for each component geometry of interest. The effective stress range versus life fatigue curve should be used to predict the fatigue life of clad specimens if the failure mode of the clad specimens is expected to be adhesive failure.

2.4 CONCLUSION

This chapter is about the summary of previous works that related to this project. The works were discussed about fatigue life prediction method, variable amplitude loading, strain-life method and stress-life method. The next chapter is about the methodology of the project.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter presents the overall methodology of the finite element based fatigue analysis. One of the essential goals in the fatigue process study is to predict the fatigue life of a structure or machine component subjected to a given stress–time history. To allow this prediction, complete information about the response and behaviour of the material subjected to cyclic loading is necessary. In addition to the characterization of the cyclic stress–strain response, quantitative information on resistance to crack is primary importance.

3.2 PROJECT FLOWCHART

The flowchart of the finite element based fatigue analysis is shown in Figure 3.1.

3.3 FINITE ELEMENT BASED FATIGUE LIFE ANALYSIS

Fatigue analysis has traditionally been performed at a later stage of the design cycle. This is due to the fact that the loading information could only be derived from the direct measurement, which requires a prototype (Bannantine et al., 1990; Stephens et al., 2000). Multibody dynamics (MBD) (Kim et al., 2002) is capable of predicting the component loads which enable designer to undertake a fatigue assessment even before the prototype is fabricated. The purpose of analyzing a structure early in the design cycle is to reduce the development time and cost. This is achieved by determining the critical region of the structure and improving the design before prototype are built and tested.

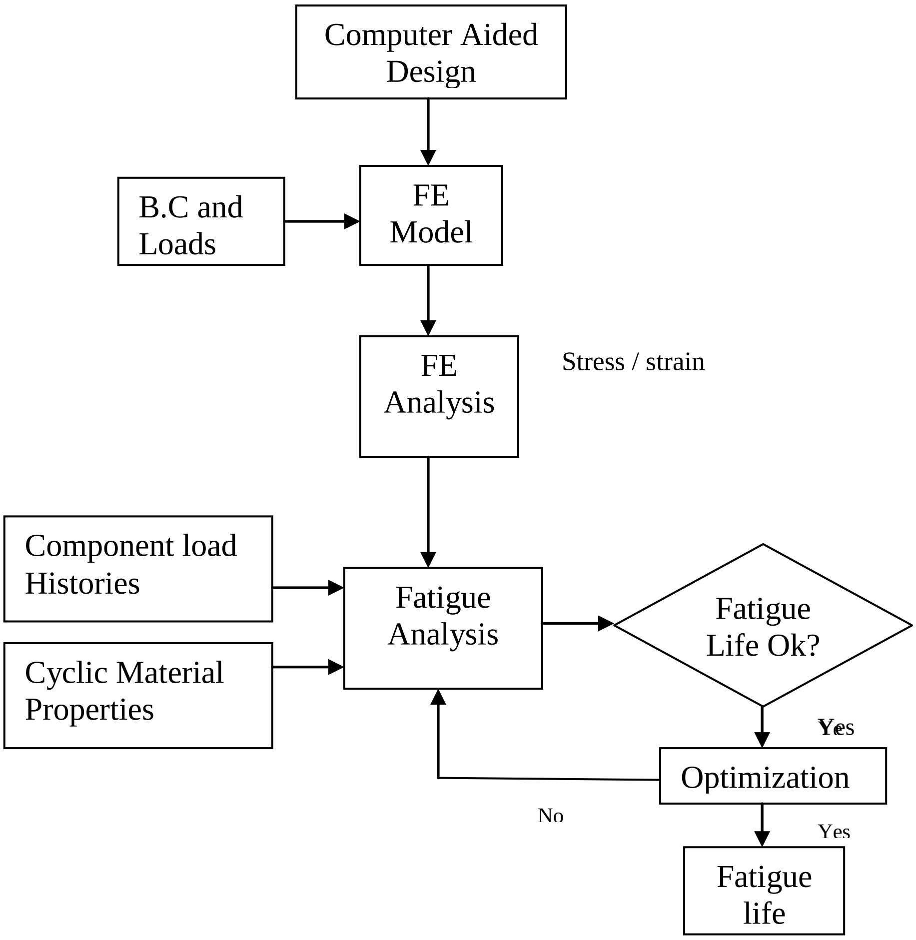

Figure 3.1: The finite element based fatigue analysis

Two computational processes are utilized to perform the finite element based fatigue analysis processes are as follows:

(i) Finite Element (FE) – to determine the stress/strain state of a component for a given load condition;

(ii) Fatigue analysis – to calculate the fatigue life for the component of interest and identify the critical locations.